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Effect of volunteer potato density on bulb onion yield and quality

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Bulb onions are poor competitors and volunteer potato, commonly observed in western USA onion fields, is difficult to manage. To improve the understanding of onion and weed interactions, relationships were quantified among volunteer potato density, onion yield, and volunteer potato tuber production using hyperbolic or linear models. Onion yield losses because of volunteer potato interference occur at densities commonly observed in the field. A volunteer potato density as low as 0.067 plants m^{-2} resulted in a 10% reduction in crop yield. Asymptotic yield loss (*A* parameter) was 100% and achieved with 4 volunteer potato plants m^{-2}. Volunteer potato competition limits onion bulb size, resulting in a lower quality and thus a less-valuable crop. Volunteer potato tuber density and biomass increased linearly with initial weed density as high as 8 volunteer potato m^{-2}. Onion yield loss from volunteer potato competition occurs to a greater extent and at a lower weed density than demonstrated in previous research on small-seeded annual weed species.

Nomenclature: Volunteer potato, *Solanum tuberosum* L. 'Russet Burbank' and 'Ranger Russet'; onion, *Allium cepa* L. 'Pinnacle' and 'Vaquero'.

Key words: Competition, economic threshold, hyperbolic model, weed density, yield loss.

Bulb onions and potatoes are important crops in western United States. As an example, Idaho, Oregon, and Washington are responsible for 35 and 54% of bulb onion and potato production in the United States, respectively (Anonymous 2003). Onions are generally grown on a 3-yr cycle and often rotated with potatoes.

Volunteer potato is a common weed in onion because commercial potato harvest operations can leave numerous tubers in the field that survive, overwinter, and persist in rotation crops. Volunteer potatoes are difficult to suppress because of large energy reserves in the tuber and the ability to resprout after chemical and mechanical control (Boydston and Seymour 2002; Williams and Boydston 2002). Current tactics used to suppress volunteer potatoes in onion include herbicides, cultivation, hand-weeding, and soil fumigation (Boydston and Seymour 2002; Boydston and Williams 2003).

Onion is susceptible to weed competition because it is slow to emerge, has a low initial growth rate, and its narrow, erect leaves produce little shade (Hewson and Roberts 1973; Wicks et al. 1973). Populations of small-seeded annual weeds such as common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) reduce onion yield 90% or more when present at densities up to 850 seedlings m^{-2} (Hewson and Roberts 1971; Shadbolt and Holm 1956). Densities of volunteer potato in spring are relatively low, often ranging from 0.4 to 10 plants m^{-2}. Response of onion total yield and bulb size distribution to volunteer potato is not currently known.

One approach to improve the knowledge of weed and crop interactions is to quantify the relationship between crop yield and weed density. Although such studies have been conducted for a number of agronomic crops, few studies have empirically quantified onion yield loss as a function of weed density (Dunan et al. 1996). The objectives of this study were to quantify the effects of volunteer potato density on yield and quality of bulb onion and to characterize the relationship between weed density and volunteer potato tuber production in bulb onion.

Materials and Methods

Irrigated field experiments were conducted at Parma, ID, Ontario, OR, and Prosser, WA, in 2002. Onions were planted 2 cm deep using a seeder equipped with four planting shoes spaced 56 cm apart. A planter with a single onion line per planting shoe was used in Washington.[1] Sites at Idaho and Oregon were planted on 28-cm-wide raised beds with double lines, spaced 7.6 cm apart, per planting shoe per bed.[2] Additional details on planting, emergence, and site characteristics are provided in Table 1.

Six weed-density treatments were established: 0, 0.5, 1, 2, 4, and 8 potato plants m^{-2}. The experimental design was a randomized complete block with four replications. Experimental units measured 7.6 m in length by 2.2 m in width (four single-line rows in Washington and four double-line rows in Idaho and Oregon). Within 2 d of onion planting, whole seed potato tubers averaging 59 g $tuber^{-1}$ were planted to simulate volunteer potatoes (Table 1). Potato tubers were hand-planted 15 cm deep either between the double onion lines (Idaho and Oregon) or within 2 cm of the single onion line (Washington). Tubers were not planted in outside rows of experimental units. At all sites, tubers were spaced equidistantly within the onion line(s).

Experimental sites were kept free of weeds other than volunteer potato by hand-weeding and herbicides. Herbicide applications included preemergence applications of 6.7 kg ai ha^{-1} DCPA and 1 kg ai ha^{-1} pendimethalin and postemergence applications of 0.2 kg ai ha^{-1} sethoxydim at one-leaf and two-leaf stage of onion. Onions were furrow irri-

Table 1. Volunteer potato and onion varieties, planting dates and configurations, soil properties, and emergence dates for experimental sites at Parma, ID, Ontario, OR, and Prosser, WA.

Location	Potato variety	Potato planting date	Onion variety	Onion planting date	Onion planting density	Onion planting configuration	Soil type[a]	Organic matter	pH	Potato emergence	Onion emergence
					seeds ha^{-1}			%			
Idaho	'Ranger Russet'	March 27, 2002	'Vaquero'	April 30, 2002[b]	391,200	Double lines, 56-cm rows	Greenleaf silt loam	1.1	7.6	May 4, 2002	May 14, 2002
Oregon	'Russet Burbank'	March 27, 2002	'Vaquero'	March 29, 2002	380,800	Double lines, 56-cm rows	Greenleaf silt loam	1.7	7.4	April 23, 2002	April 14, 2002
Washington	'Russet Burbank'	April 24, 2002	'Pinnacle'	April 22, 2002	261,800	Single line, 56-cm rows	Warden silt loam	1.1	7.2	May 24, 2002	May 8, 2002

[a] Greenleaf silt loam (fine-silty, mixed, superactive, mesic Xeric Calciargids); Warden silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids).
[b] Onions were originally planted March 28, 2003 at Idaho. However, wet and cool soils resulted in high seedling mortality and onions were replanted April 30, 2002.

gated (Idaho and Oregon) or sprinkler irrigated (Washington) and fertilized according to soil tests and university recommendations (Pelter et al. 1992). Lambda-cyhalothrin was applied in Oregon and Washington as needed following labeled recommendations to control thrips populations.

After crop senescence, onions from 6 m (Idaho and Washington) or 7.5 m (Oregon) of each plot were hand-harvested October 8, September 15, and September 9, 2002, at Idaho, Oregon, and Washington, respectively. On the basis of maximum onion bulb diameter, onions were sorted using commercial market-class grades, including small ($<$ 5.7 cm), medium (5.7 to $<$ 7.6 cm), jumbo (7.6 to $<$ 10.2 cm), colossal (10.2 to $<$ 10.8 cm), and super colossal ($\geq$ 10.8 cm).[3] The number of bulbs and total fresh mass of each market class were recorded. Within 1 d of onion harvest, three volunteer potato plants per plot were randomly selected and examined for tuber number and fresh biomass.

Statistical Analyses

Relative yield was calculated within each block as yield at a given volunteer potato density (N) divided by weed-free yield within that block. Yield loss was calculated as unity minus relative yield. Cousens (1985) reported that crop yield loss could be related to weed density using a rectangular hyperbola equation:

$$Y_l = \frac{I^*N}{1 + \dfrac{I^*N}{A}} \qquad [1]$$

where Y_l is percent yield loss, N is weed density (expressed as plants m^{-2}), I is percentage yield loss as weed density approaches zero, and A is the upper asymptote or maximum yield loss. Equation 1 was fit to onion yield loss at each location, and parameter estimates were determined using nonlinear regression. Final volunteer potato tuber density and biomass were related to initial tuber density for each location using linear regression techniques (SAS 1998).

For both onion yield loss and potato production data, the extra sum of squares principle for nonlinear regression analysis (Ratkowsky 1983) was used to evaluate the similarity of parameter estimates among locations. Comparisons were made by calculating a variance ratio of individual and pooled residual sums of squares (Lindquist et al. 1996). If parameter estimates were constant across locations, data were pooled among locations. Yield loss parameter estimates were then used to determine the volunteer potato density needed to result in predetermined levels of yield loss of 2.5, 5.0, and 10.0%.

Results and Discussion

Weed-free onion yields were 48,300, 102,900, and 56,600 kg ha^{-1} at Idaho, Oregon, and Washington, respectively. Average time from onion planting to 50% emergence was 15 d, whereas 32 d were required for volunteer potato emergence (Table 1). Volunteer potato emerged 9 and 16 d after onion emergence in Oregon and Washington, respectively, and approximately 10 d before onion emergence in Idaho (Table 1). Onions were originally planted on March 28, 2002, in Idaho, but cool, wet soils after planting resulted

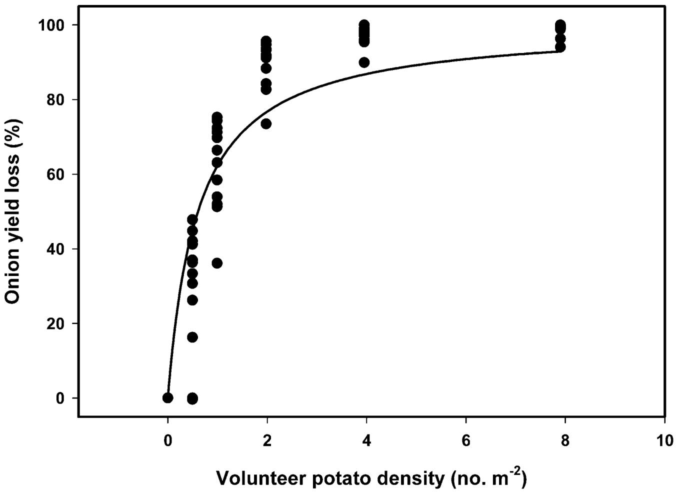

FIGURE 1. Percent onion yield loss as a function of volunteer potato density. The regression equation is yield loss = $(165x)/(1 + 165x/100)$ ($r^2 = 0.89$).

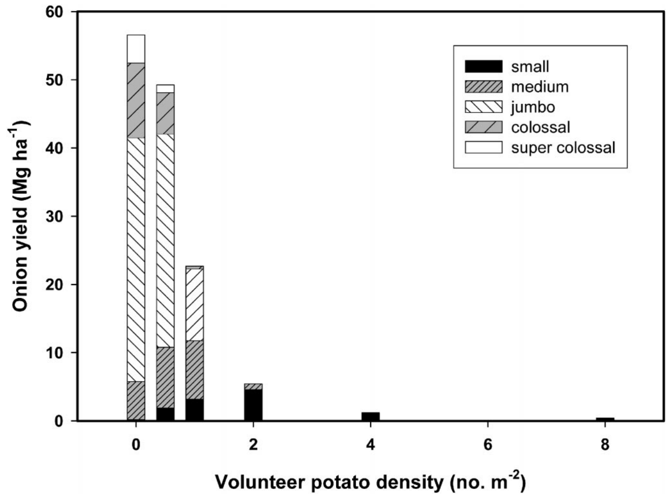

FIGURE 2. Effect of volunteer potato density on onion yield by market class in Washington. Market classes are based on maximum onion bulb diameter; small (< 5.7 cm), medium (5.7 to < 7.6 cm), jumbo (7.6 to < 10.2 cm), colossal (10.2 to < 10.8 cm), and super colossal (≥ 10.8 cm).

in high seedling mortality. Onions were replanted about 4 wk after volunteer potato.

Yield loss parameter estimates were constant among locations (data not shown); therefore, data were pooled.

Volunteer potato eliminated onion production at relatively low weed densities and maximum yield loss (A) was 100% (Figure 1). Yield losses in these trials were more than in a previous Texas study, where over 6 yr, common sunflower (*Helianthus annuus* L.) and London rocket (*Sisymbrium irio* L.) reduced onion yield 0 to 53% (Menges and Tamez 1981b). However, Hewson and Roberts (1971) found yield reductions exceeded 90% when prostrate knotweed (*Polygonum aviculare* L.) and annual bluegrass (*Poa annua* L.) occurred at 150 to 850 plants m^{-2}. Results of our work are more comparable with the percentage onion yield reductions that Boydston and Seymour (2002) reported with volunteer potato at 7 plants m^{-2}.

An I value of 165 was calculated in our study (Figure 1). Across 13 site-years, Lindquist (2001) found that I ranged from 2.8 to 33.8 for velvetleaf (*Abutilon theophrasti*) interference in corn (*Zea mays* L.). Lower estimates of I also have been found for annual grass and broadleaf weeds in wheat (*Triticum aestivum* L.) and soybeans [*Glycine max* (L.) Merr.] (Cowan et al. 1998; Pester et al. 2000). Large differences in estimates of I found in this work compared with annual weeds in corn, wheat, and soybean reflect the competitive ability of volunteer potato propagated from tubers and low tolerance of onion to the weed.

A relatively small number of volunteer potatoes had a large impact on onion yield. Volunteer potato density at 0.016, 0.032, and 0.067 m^{-2} resulted in an estimated 2.5, 5, and 10% yield loss. Our results are in contrast to previously published work in onion (Dunan et al. 1996; Menges and Tamez 1981a). Dunan et al. (1996) found that relative yield stabilized at approximately 20 plants m^{-2} for redroot pigweed and common purslane (*Portulaca oleracea* L.). Maximum yield loss occurred at approximately 4 volunteer potatoes m^{-2} in our study (Figure 1). Although volunteer potato is more competitive than other weeds studied, our results are in general agreement with those of Dunan et al. (1999) in that relatively low weed densities have a large impact on onion yield and the asymptotic yield loss is 100%.

Yield of each market class was significantly affected by weed density. With increasing volunteer potato density, lower yields were observed in valuable market classes such as jumbo, colossal, and super colossal (Figure 2). Overall onion density was less affected by increasing volunteer potato density; yet, onion bulb size was reduced, resulting in fewer large (e.g., jumbo) bulbs and a higher percentage of unmarketable (small) bulbs (Figure 3). Although volunteer potato at 2 plants m^{-2} resulted in similar total number of bulbs as the weed-free treatment, 97% of the bulbs were unmarketable. Similar results were found at Idaho and Oregon (data not shown). Roberts (1973) reported that the number and size of leaves at time of bulbing is critical in potential size of bulbs at harvest. Because weed interference in onion results not only in lower onion yields but also in reduced per unit value of those plants that survive, weed

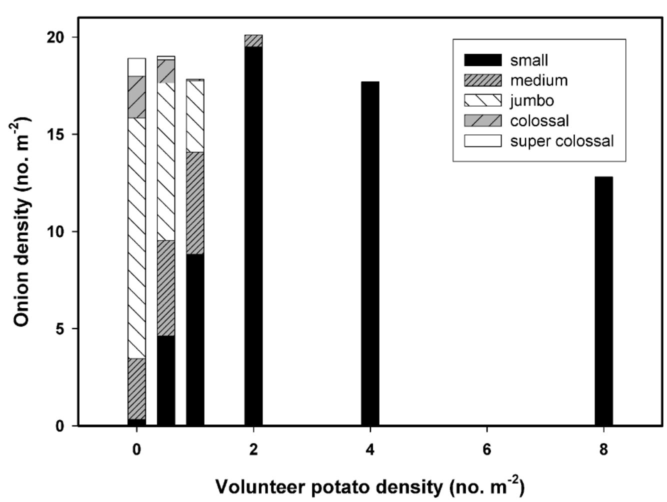

FIGURE 3. Effect of volunteer potato density on onion number by market class in Washington. Market classes are based on maximum onion bulb diameter; small (< 5.7 cm), medium (5.7 to < 7.6 cm), jumbo (7.6 to < 10.2 cm), colossal (10.2 to < 10.8 cm), and super colossal (≥ 10.8 cm).

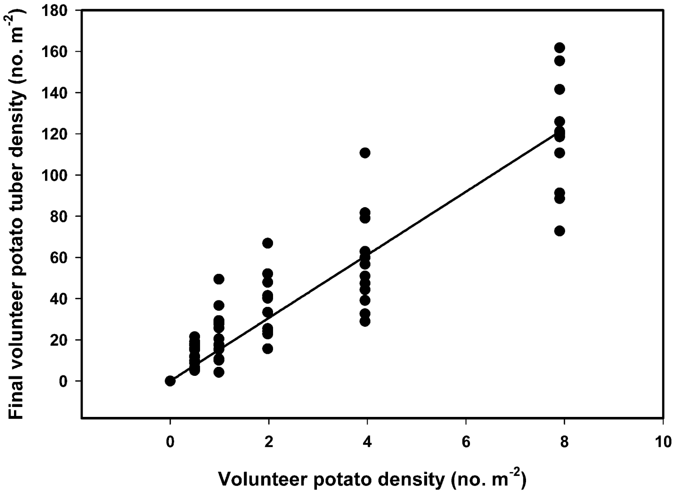

FIGURE 4. Final volunteer potato tuber density as a function of initial volunteer potato density. The regression equation is final tuber density = $15.3x$ ($r^2 = 0.90$).

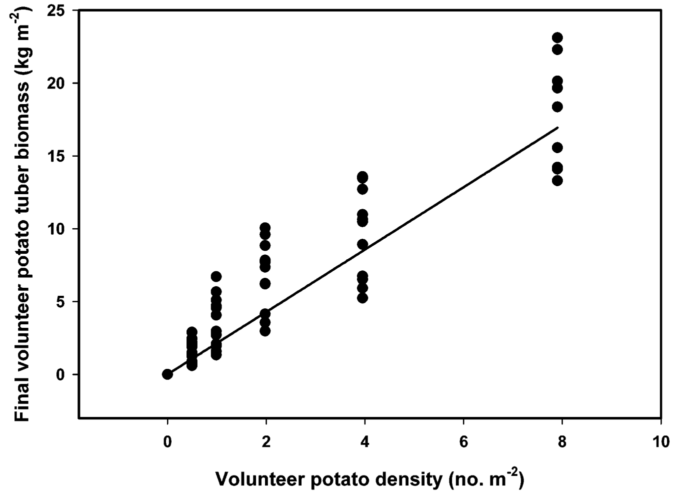

FIGURE 5. Final volunteer potato tuber biomass as a function of initial volunteer potato density. The regression equation is final tuber biomass = $2.14x$ ($r^2 = 0.83$).

density would most likely have an even greater effect on actual market value than total crop yield described here.

Regression parameter estimates of final volunteer potato tuber density and biomass were constant among locations (data not shown); therefore, data were pooled. Final volunteer potato tuber density and biomass increased linearly with initial weed density over the range of volunteer potato densities evaluated. For each potato plant present in the treatments, 15.3 tubers were produced by season-end (Figure 4). Tuber biomass increased similarly, with each volunteer potato plant contributing 2.14 kg of tubers (Figure 5). Potato tuber size is an important factor in managing the weed because increasing tuber size increases yield potential (Wakankar 1944) and decreases susceptibility to some herbicides (Lutman 1977). Rate of volunteer potato tuber production conceivably would decrease at higher plant densities but the practical value of quantifying tuber production beyond 8 volunteer potatoes m^{-2} is negligible because onion yield loss approaches 100% within the range of weed densities studied here. Results demonstrate the potential for volunteer potato persistence in onion.

Integrated weed management strategies that combine mortality and fitness-reducing events are needed to improve suppression of volunteer potato. Volunteer potato densities as low as 0.032 plants m^{-2} (320 plants ha^{-2}) can inflict onion yield losses of 5%. Because crop quality also is reduced by weed competition, as measured by onion bulb diameter, economic losses are likely higher than 5% at such a weed density. Furthermore, tuber production of volunteer potatoes in onions is high, contributing to weed persistence in potato cropping systems. New incidences of late blight (*Phytophthora infestans* Mont.) infection have been attributed to infestations of volunteer potato in rotation crops, and volunteer potato can serve as an alternate host for other serious potato pests as well (Ellis 1992; Thomas 1983).

Sources of Materials

[1] Planter, Singulaire 785, Stanhay Webb Ltd., Houghton Road, Grantham, Lincs NG31 6JE, U.K.

[2] Planters, Mel Beck Precision Planters, 214 Thunderegg Boulevard, Nyssa, OR 97913.

[3] Market-class grade of onion, Idaho-E. Oregon Onions, 118 North Second Street, P.O. Box 909, Parma, ID 83660.

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